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WANL-TNR-042

MODES OF FAILURE ANALYSIS SUMMARY NERVA B-2 REACTOR

(Title Unclassified)

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Astronuclear Laboratory
Westinghouse Electric Corporation

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34

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MODE OF FAILURE ANALYSIS SUMMARY

NERVA B-2 REACTOR

By

R. A. Neal

March 9, 1962

WESTINGHOUSE ELECTRIC CORPORATION

ASTRONUCLEAR LABORATORY

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TABLE OF CONTENTS

LIST OF FIGURES AND TABLES

MODES OF FAILURE ANALYSIS

NERVA B-2 REACTOR

SUMMARY

A failure mode analysis of the NERVA B-2 reactor design has been made. The results are summarized with emphasis on the design recommendations to improve the overall reliability of the reactor.

MODES OF FAILURE ANALYSIS

NERVA B-2 REACTOR

INTRODUCTION

In the preliminary design phase of the NERVA reactor, several basically different designs have been considered. One of these contains a bottom supported core and is identified as the NERVA B-2 reactor design. Reliability, as stated in the NERVA contract, is of extreme importance. Because of this importance, a failure mode analysis of the NERVA B-2 reactor design was considered desirable. This report presents the results of the failure mode analysis and indicates areas in which design changes may be made to improve the reliability of the design.

RECOMMENDATIONS

Future design effort on the NERVA B-2 reactor should adequately consider the following recommendations:

A. Damage of cylinders due to relative rotation should be prevented.

B. Axial gaps in the graphite reflector, caused by core expansion, should be examined and evaluated with respect to possible detrimental effects.

C. The coefficient of friction for graphite on graphite should be examined to ensure that sliding will occur at the various inclined planes.

It is further recommended that the following design actions be considered as pertinent to the improvement of the overall reliability of the NERVA B-2 reactor.

1. Cooling passages should be protected from clogging.
2. Sticking of control drums should be prevented.
3. Holding of the boral control plate should be improved.
4. Small diameter cooling holes in control drum top plate should be used.
5. Design of control drum stop plate, spring and spring cover should be improved.
6. Core loading spring ends should be retained.
7. Orientation of control drum drive shaft with control drum should be such that this will not depend upon a loose piece.
8. Possibility of lithium hydride entering core should be prevented.
9. Possibility of high density hydrogen entering core should be prevented.
10. Cooling flow through the shield should be controlled.

DESCRIPTION OF NERVA B-2 REACTOR DESIGN

The NERVA B-2 reactor design which was used for the analysis presented in this report is shown in Figure 1. Figures 2, 3, 4, and 5 show the reactor in schematic form.

The NERVA B-2 reactor design is based on the KIWI B-2 design. In this design the core is supported by a bottom plate made of graphite. Loads on the core are carried by this plate, and then to the pressure vessel, by an inclined plane. A cooled graphite reflector surrounds the core, and a one piece beryllium reflector with rotatable control drums surrounds the graphite reflector. The assembled reactor is inserted in the pressure vessel from the top. To serve as a propellant tank shield, a lithium hydride shield is located at the top of the core structure. Heated hydrogen is removed through the shield and drives the turbine, thus the pump. Additional heat is added as the hydrogen passes through the nozzle skirt.

FAILURE MODE ANALYSIS PROCEDURE

Since detail drawings for the NERVA B-2 reactor are not in existence, the design is, in a sense, incomplete; and the failure mode analysis must start by examining the general layout or assembly drawing. From this drawing a parts list is created. To provide identification each part is assigned a planning parts list number. This number will be used throughout the analysis. In addition, when detail drawings become available, this number will be associated with the part number; however, if there is future redesign, there may be several part numbers that would be identified with a single planning parts list number. The planning parts list number is used primarily for planning and is most useful prior to the assignment of part numbers.

Each part, now identified by a planning parts list number (see Table I), is considered separately; part function is established; and the details of the part, as visualized from the available information, are studied. For each part, every conceivable mode of failure is noted, and the probable cause or causes of each mode is recorded. How the mode of failure affects the operation of the engine is next evaluated and enumerated.

Action to eliminate or prevent each mode of failure is determined. This recommended action may: (1) require special quality control effort during the manufacturing phase and consist of special tests, measurements, or procedures; (2) require some special laboratory tests, such as environmental tests, to demonstrate the design integrity; and (3) suggest additional design effort. During the preliminary design phase, the recommended actions can greatly assist in the attainment of a design with inherently high reliability. It is for this reason that the failure mode analysis of this report has been made.

Results of the failure mode analysis are summarized on a special form (see Table II). This form lists the part name, planning parts list number, mode of failure, hazard, effect on thrust, cause of failure, recommended methods to eliminate or prevent failure, and disposition. In the future, the disposition column is to be used to note the action actually taken.

Since the summary of Table II is aimed at recommending design actions to improve the reliability of the design, the recommended actions are discussed, in greater detail, in the following paragraphs.

RESULTS AND DISCUSSION

The design of the NERVA B-2 reactor, as shown in Figures 1, 2, 3, 4, and 5 is incomplete in that no detail drawings and, in most cases, no detail design analyses have been made. Extensive design effort would be required before a completely satisfactory design would be available. However, at this early stage in the design, a failure mode analysis is highly desirable so that changes which can aid in the attainment of a design with higher reliability can be recognized and design action taken before changes would be difficult to make.

During the course of the failure mode analysis several features in the design were observed as requiring additional design effort before these can be considered satisfactory for use in the design. These features are to be investigated thoroughly before the design reaches its final form. Though not noted in the detail failure mode analysis, these features are listed below as reminders for adequate consideration in future design work on the NERVA B-2 reactor:

A. *Suitable arrangements should be provided to prevent damage of the many* cylinders due to relative rotation.

B. Radial expansion of the core when heated will cause axial gaps in the graphite reflector. That these gaps are not going to cause overheating of parts external to the graphite reflector should be determined. If the gaps are detrimental, these should be eliminated or the design modified to reduce the heat flow through the gaps.

C. Sliding of the bottom support plate on the inclined ramp may present some serious design problems. If the coefficient of friction of graphite on graphite is too high to permit sliding of the parts, the core support structure can be overstressed to the point of failure. Failure of the core support structure in this manner would result in a catastrophic failure of the reactor. The detail design of the core support, the top core support, and the reflector cylinder segments must consider the sliding of graphite on graphite; and design action must be taken to assure that seizure and sticking can never occur.

Table II presents the "Failure Mode Analysis Summary." This special form summarizes the results of the malfunction analysis and contains the following information:

1. Part Name
2. Planning Parts List Number
3. Mode of Failure
4. Hazard
5. Effect on Thrust

6. Cause of Failure

7. Recommended Methods to Eliminate or Prevent Failure

   a. Testing during manufacturing

   b. Laboratory testing during development

   c. Design

8. Disposition (Reserved for future use.)

Since the design of the NERVA B-2 reactor is a preliminary one, the recommended design changes will be the most effective items reported in the summary of Table II. It is certain that if the failure modes can be eliminated by design changes, the inherent reliability will be improved. This report is therefore concerned primarily with the design recommendations. During the detail design of the NERVA B-2 reactor, the following items should be considered as potential improvements to obtain a higher inherent reliability.

1. Protect cooling passages from clogging. There are cooling passages through the graphite reflector, beryllium reflector, control drums, core and shield and over the pressure vessel. In most cases the cooling flow is vital to continued operation. This cooling flow must be maintained or serious failure will result. The use of screens, strainers, traps, etc., will improve the inherent reliability. Cleanliness, care and quality control can assist by eliminating many sources of debris; however, there are sources of debris that will defy detection. When one particle, .100-.150" across its maximum dimension, can cause catastropic failure of the reactor by blocking any one of the 8029 holes in the core, it appears most logical to provide additional protection.

2. Prevent Control Drum Sticking. The control drums must be prevented from sticking in the open position. With the fast control planned, the drums are forced into the

open position at every increasing power surge. Sticking of only one drum in the open position can cause a local core hot spot that will result in catastrophic core failure. In the design review it is apparent that there will be temperature gradients through the control drum, resulting in distortion. Sufficient clearance must be provided. It would seem desirable to do something in the detail design to minimize sticking in the event of rubbing. Closely spaced circumferential V-grooves along the surface of the drum would be effective at reducing sticking since the apex of the aluminum could wear off rapidly and allow the drum to increase its clearance locally. This and other schemes can be quite important in minimizing the effect of rubbing.

The bottom control drum bearing is designed such that the a. differential expansion is taken out by the outside diameter of the bearing sliding in the bearing holder. This is likely to promote sticking; thus, the control drum can stick and bind. The use of a roller bearing at this location would prevent this type of failure. In any case, a self aligning bearing should be used because of the distortion that takes place in the reflector assembly.

Design of a failsafe control is very important. Failure in the control circuits that will cause a single control drum to go to the full open position must be avoided at all costs. It is expected that many such failures may occur and design action to eliminate these will prove to be most helpful in improving the inherent reliability.

3. Improve holding of boral control plate. The boral plate is held between the aluminum cover and the beryllium control drum. Differential expansion can cause the plate to loosen or to be held too tightly. If too loose, it can rattle due to vibration and break; if too tight, it may be distorted sufficiently to break. The design should be reviewed to make sure that this critical part is properly held such that it will not break.

4. Use small diameter cooling holes in control drum top plate Generation of chips due to vibration and distortion inside the control drum aluminum sleeve may be unavoidable. These chips should not be permitted to enter the core. The outlet cooling holes should not be any larger than one third the diameter of the core inlet holes. Any particle that gets outside the drum sleeve can then pass unobstructed through the core.

5. Improve design of control drum stop plate, spring and spring cover. The stop plate and spring have axial and radial freedom, being retained by a fixed cover welded to the bottom support ring Vibration can cause wear and failure of these parts. Attachment of the stop plate and spring should be reviewed. It is suggested that these be individually attached, with all axial or radial play removed Dependence on a welded-on sheet metal cover should be avoided.

6. Retention of core loading spring ends. It is reasonable to assume that sooner or later one of the core loading springs will fail. If the two parts are not retained, these can get into the core inlet and can block holes in the core causing catastrophic core failure, even though the support of the core will be unaffected by the loss of a single spring. It is suggested that the spring supports be arranged to retain each end. The last coil of the spring can be snapped into a groove, retaining the spring in the event of failure.

7. Means to orient control drum drive shaft with control drum that does not depend upon separate loose piece. The design shown indicates a separate loose dowel pin in the connecting spline. The dowel pin can fall out at assembly, or can be left out. In either case the shaft may be assembled incorrectly. The results of such an assembly can be a nuclear accident.

8. Prevent lithium hydride from entering the core. Carbon is highly corrosive in the presence of lithium hydride. Design effort to prevent LiH entering the core will increase the inherent reliability.

9. Prevent high density hydrogen from entering the core. Gaseous hydrogen below 90°R and liquid hydrogen at 37.5°R must not enter the core. High density hydrogen entering the core can cause increased nuclear activity that is very difficult to control with the rotating drums of the NERVA reactor. In addition to the physical damage caused by such uncontrollability and the safety aspects, there is the possibility of damage to the core from temperature shock when low temperature liquid hydrogen contacts the core. During a start it is planned to program the starting events in sequence and depend upon thermal capacity, flow characteristics, etc. to make sure that high density hydrogen never reaches the core. The inherent reliability of the reactor can be improved by design action that can positively assure that high density hydrogen can never enter the core. From the safety standpoint this action may be mandatory.

10. Control of cooling flow through the shield. The shield becomes heated by absorbing neutrons in the LiH and gamma radiations in the stainless steel. The temperature of the shield is determined by the flow of hydrogen through the shield. The flow of hydrogen is controlled by the flow passages through the shield, the piping and valving to the turbine, the passages through the nozzle, and the characteristics of the discharge nozzle or nozzles. Of these, Westinghouse is only responsible for the shield flow passages. Design variations, malfunctions, etc., in the portion of the system outside Westinghouse responsibility can have a profound effect upon the satisfactory operation of the shield. Care should be taken such that these outside influences are satisfactory for the shield design.

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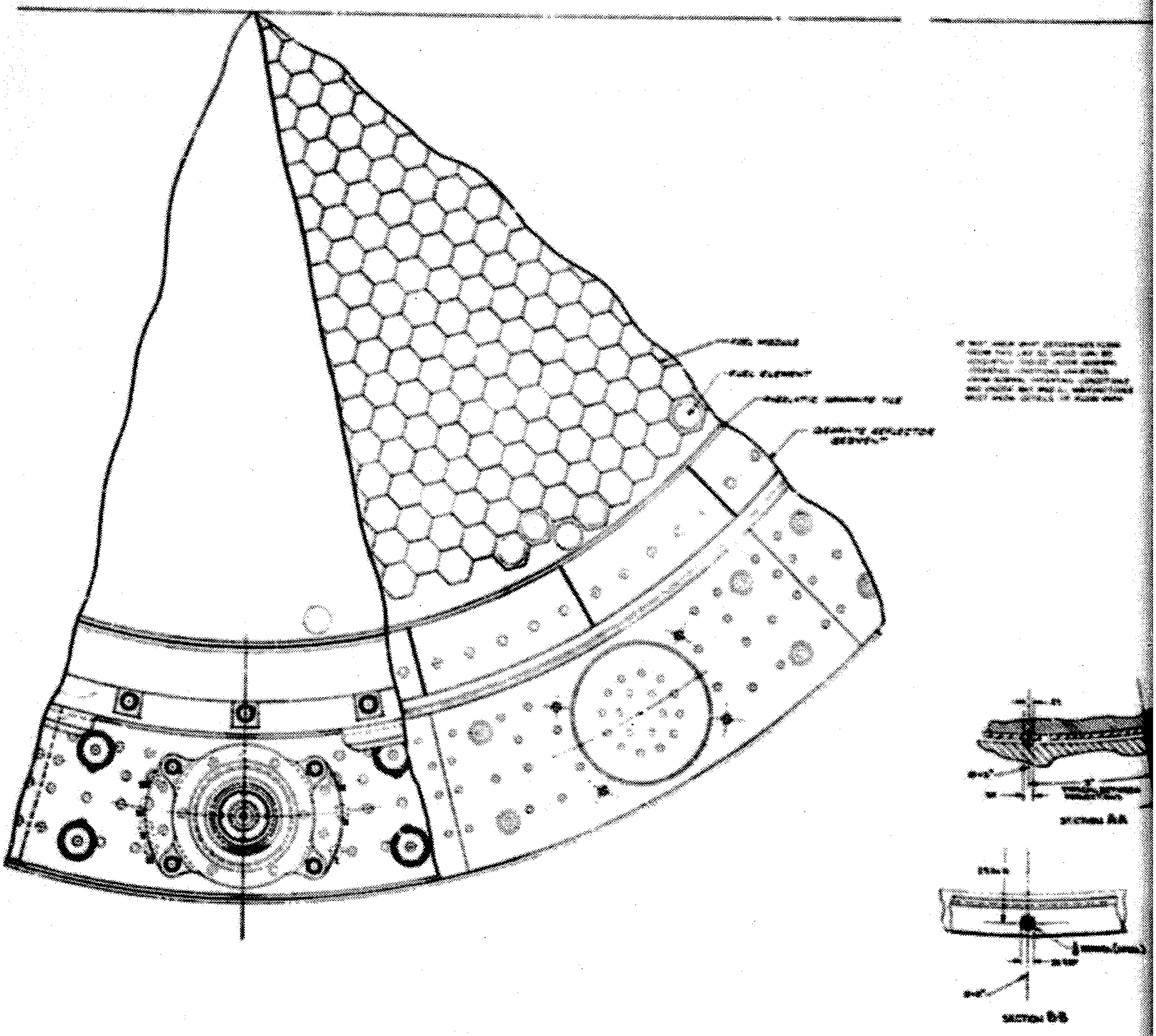

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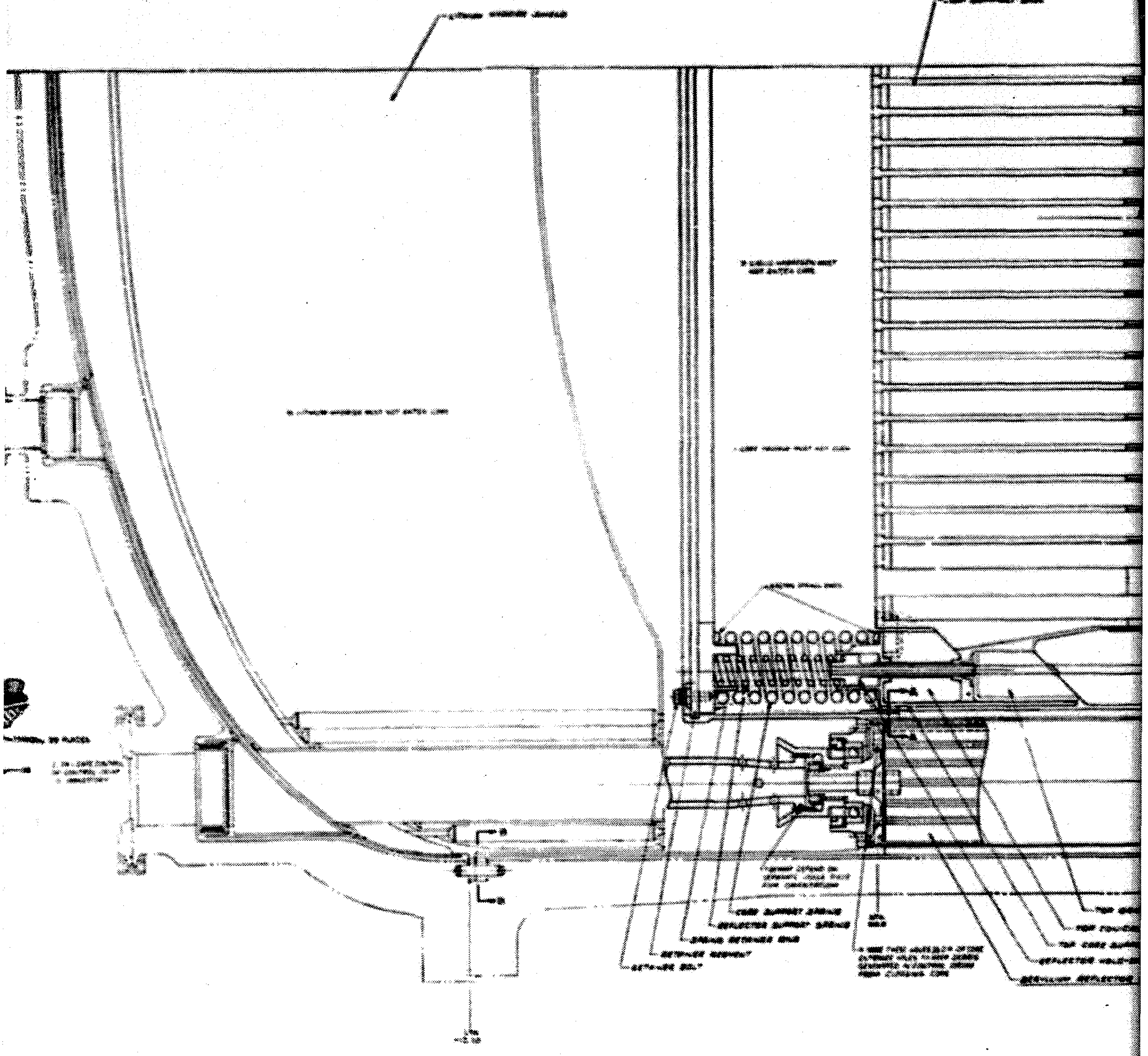
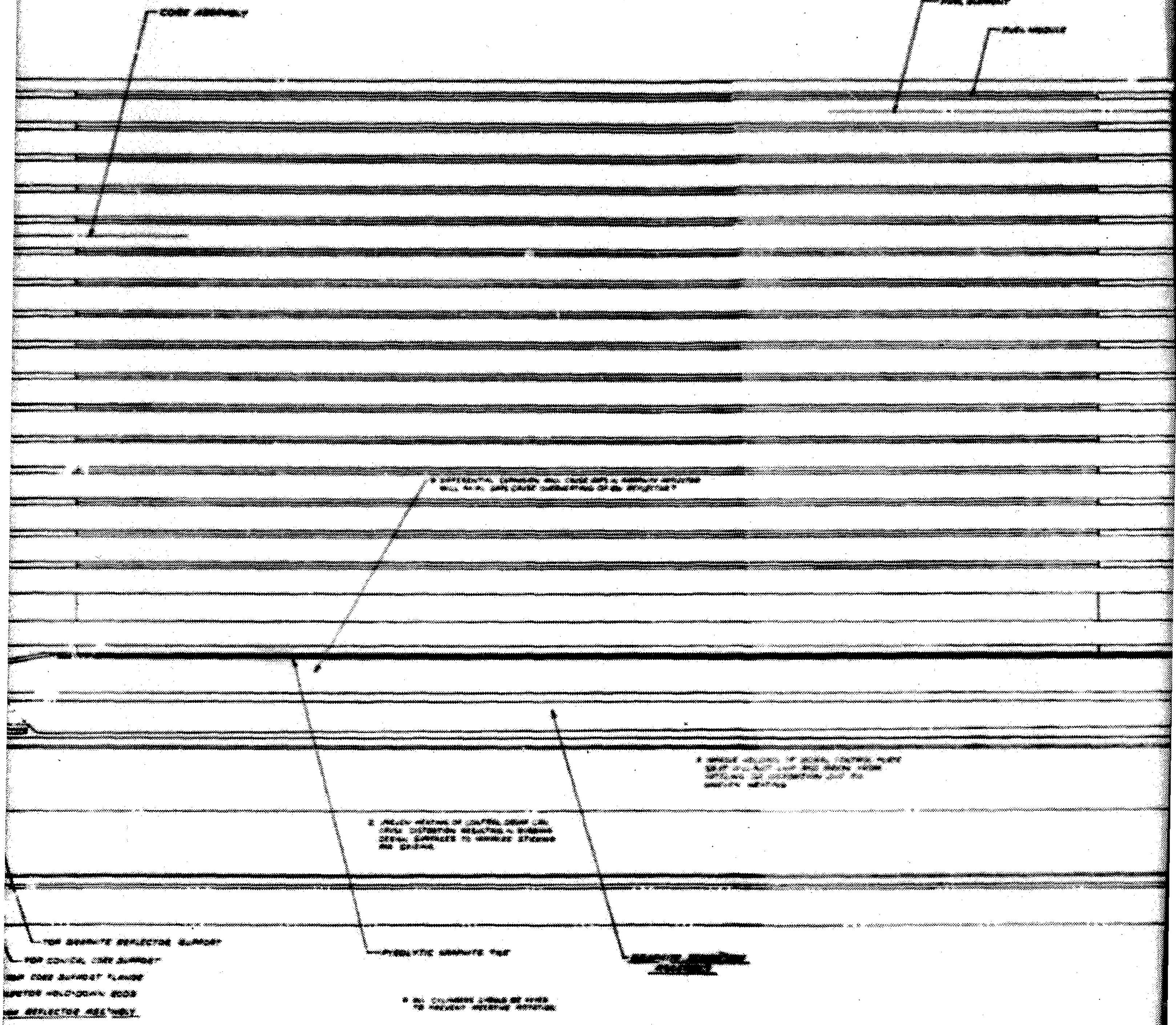


2


CORE ASSEMBLY
TOP GRAPHITE REFLECTOR SUPPORT
PYROLYTIC GRAPHITE TILE

3

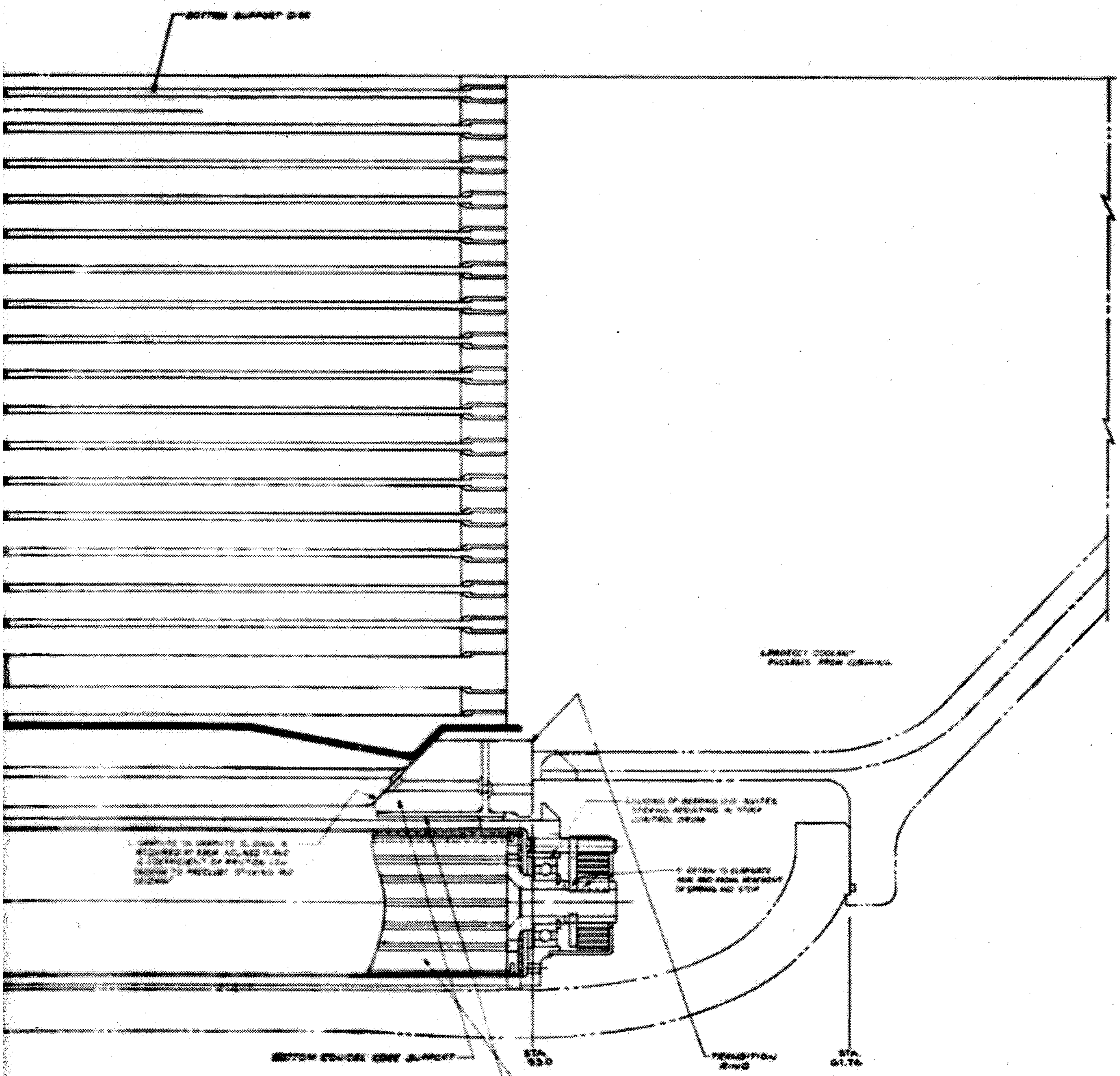


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Figure 1 702J134

NERVA Reactor Based on KIWI B-2 - Top Loaded Core, Heated Bleed

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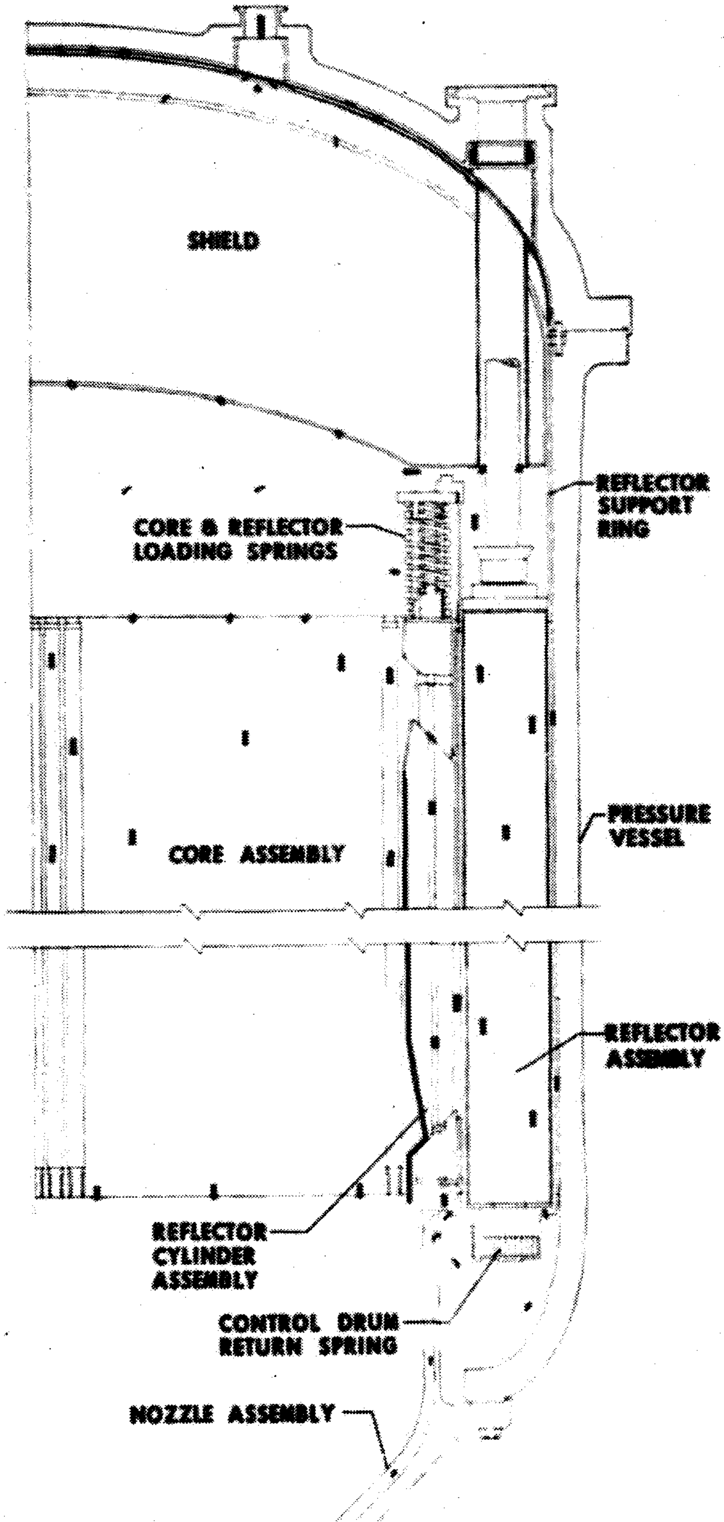

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Figure 2
Schematic of NERVA B-2 Engine

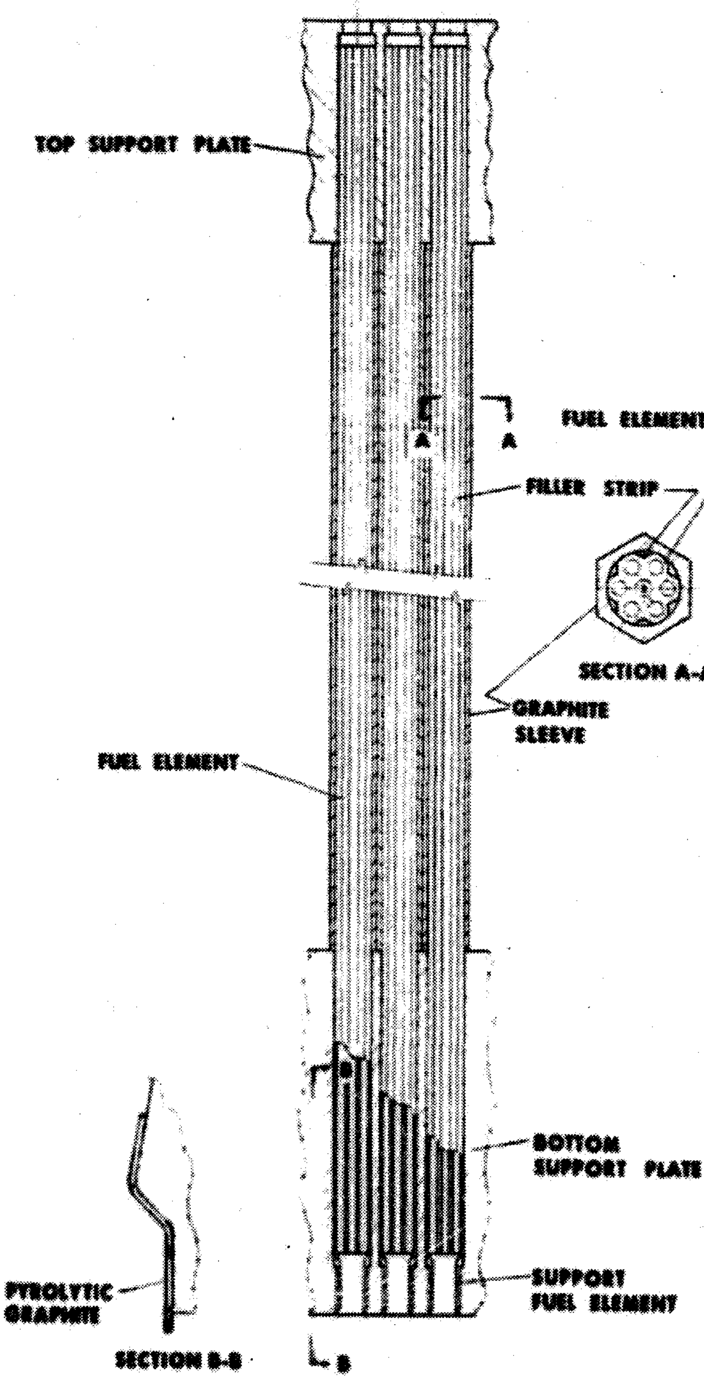

Figure 3

Core Details of NERVA B-2 Reactor

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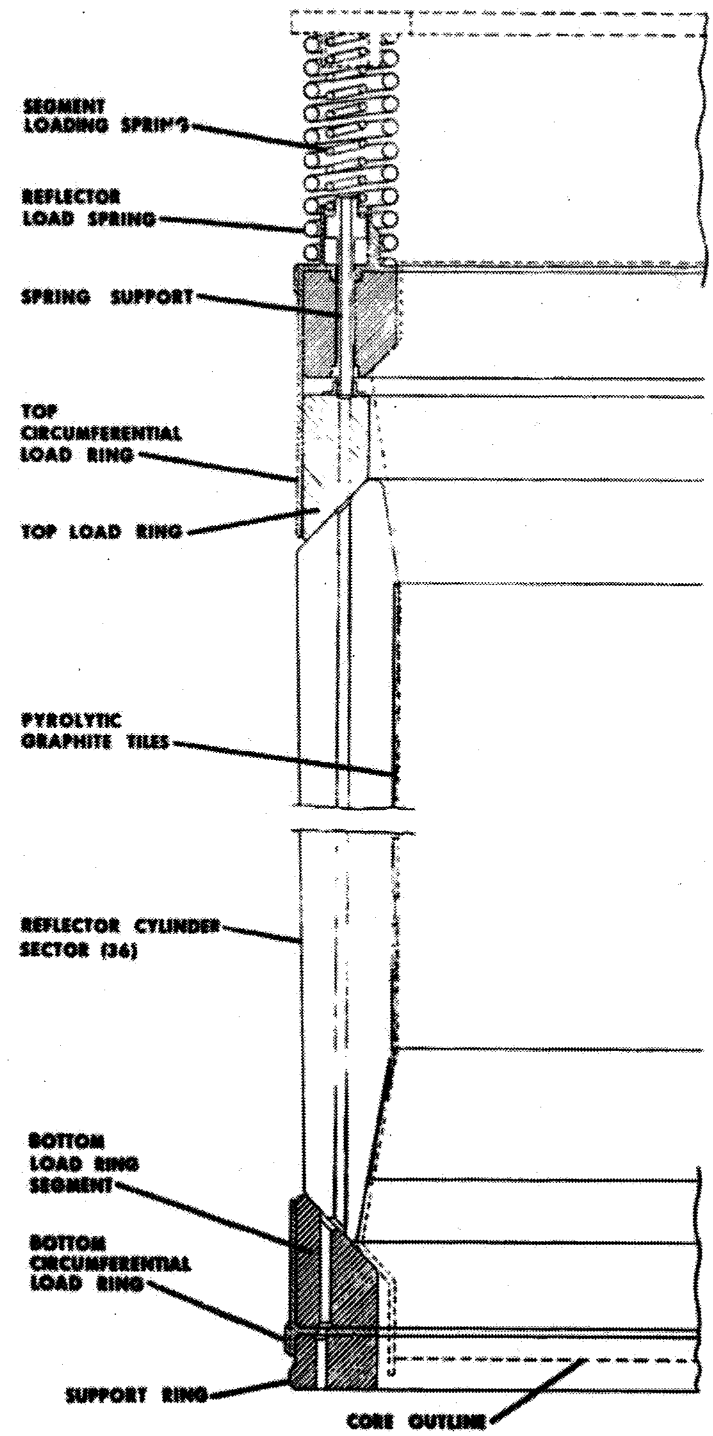

Figure 4
Reflector Cylinder Assembly of NERVA B-2 Reactor

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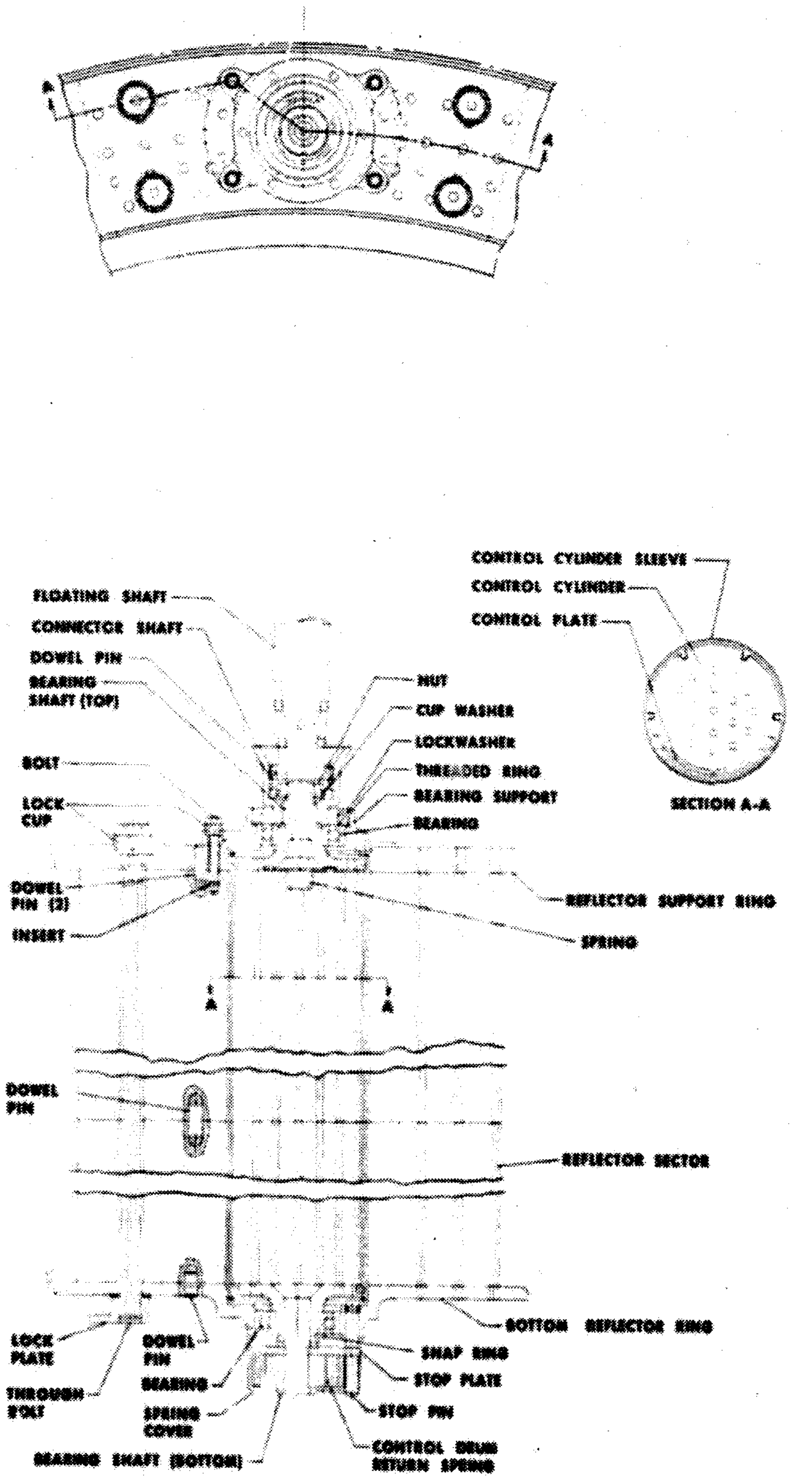

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Figure 5

Reflector Assembly of NERVA B-2 Reactor

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PLANNING PARTS LIST TITLE: NERVA B-2 REACTOR		TABLE I	DATE 1-8-62 REVISION 0
NUMBER	**PART NUMBER**	**QUANT.**	**PART NAME**
D6.2.0.0.0	No Part Numbers Available	1	Reactor Section Axial B-2 Top Loaded, Heated Bleed
D6.2.1.0.0		1	Core
D6.2.1.1.0		1	Core Assembly
D6 2.1.1.1		1	Top Support Plate
D6.2.1.1 2		1	Bottom Support Plate
D6.2.1.1.3		1147	Support Fuel Element
D6.2.1.1.4		1147	Graphite Sleeve
D6.2 1.1.5		1147	Fuel Element
D6.2.1.1.6		As req'd.	Filler Strip
D6.2.1.1.7		As req'.d.	Pyrolytic Graphite Plates
D6.2.1.2.0		1	Reflector Cylinder Assembly
D6.2.1.2.1		1	Support Ring
D6.2.1.2.2		1	Bottom Circumferential Load Ring
D6.2.1.2.3		36	Bottom Load Ring Segments
D6.2.1.2.4		36	Reflector Cylinder Sector
D6.2.1.2.5		As req'd.	Pyrolytic Graphite Tiles
D6.2.1.2.6		36	Top Load Ring Segments
D6.2.1.2.7		1	Spring Support
D6.2.1.2.8		1	Top Support Ring
D6.2.1.2.9		1	Top Circumferential Load Ring
D6.2.1.2.10		36	Segment Loading Spring
D6.2.1.2.11		36	Reflector Load Spring
D6.2.1.2.12		1	Spring Support Ring
D6.2.2.0.0		1	Reflector and Control Element
D6.2.2.1.0		1	Reflector Support Ring (Core Support Structure)

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PLANNING PARTS LIST		TABLE I	DATE 1-8-62
TITLE: NERVA B-2 REACTOR			REVISION 0

NUMBER	PART NUMBER	QUANT.	PART NAME
D6.2.2.2.0	No Part Numbers Available	24	Reflector Sector
D6.2.2.3.0		1	Bottom Reflector Ring
D6.2.2.4.0		12	Dowel Pin
D6.2.2.5.0		12	Dowel Pin
D6.2.2.6.0		12	Dowel Pin
D6.2.2.7.0		48	Through Bolt
D6.2.2.8.0		12	Lock Plate
D6.2.2.9.0		48	Lock Cup
D6.2.2.10.0		12	Control Drum
D6.2.2.10.1		1	Control Cylinder
D6.2.2.10.2		1	Control Plate
D6.2.2.10.3		1	Control Cylinder Sleeve
D6.2.2.10.4		1	Spring
D6.2.2.10.5		1	Bearing Shaft (Top)
D6.2.2.10.6		1	Bearing Shaft (Bottom)
D6.2.2.11.0		24	Bearing
D6.2.2.12.0		12	Snap Ring
D6.2.2.13.0		12	Stop Plate
D6.2.2.14.0		12	Stop Pin
D6.2.2.15.0		12	Control Drum Return Spring
D6.2.2.16.0		12	Spring Cover
D6.2.2.17.0		48	Insert Heli-coil
D6.2.2.18.0		1	Bearing Support
D6.2.2.19.0		48	Bolt
D6.2.2.20.0		48	Lock Cup
D6.2.2.21.0		12	Threaded Ring
D6.2.2.22.0		12	Lock Washer

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PLANNING PARTS LIST
TITLE: NERVA B-2 REACTOR

TABLE I

DATE 1-8-62
REVISION 0

NUMBER	PART NUMBER	QUANT.	PART NAME
D6.2.2.23.0	No Part Numbers Available	12	Connector Shaft
D6.2.2.24.0		12	Nut
D6.2.2.25.0		12	Cup Washer
D6.2.2.26.0		12	Dowel Pin
D6.2.2.27.0		12	Floating Shaft
D6.2.3.0.0		---	Core Support Structure (Part of Reflector and Control Element - See D6.2.2.1.0)
D6.2.3.1.0		1	Core Support Ring
D6.2.3.2.0		4	Core Support Ring Retaining Segments
D6.2.3.3.0		36	Bolts
D6.2.3.4.0		36	Lock Cup
D6.2.4.0.0		1	Shield Primary (Inside)
D6.2.4.1.0		1	Shield
D6.2.4.2.0		1	Baffle

TABLE II

FAILURE MODE ANALYSIS SUMMARY

NERVA B-2 REACTOR

LIST OF ABBREVIATIONS AND SYMBOLS USED

VIB.	-	Vibration
T	-	Temperature
H_2	-	Hydrogen
QC	-	Quality Control
E	-	Environmental Test
X	-	X-ray
INT.	-	Internal
P.	-	Pressure
Ass'y.	-	Assembly

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FAILURE MODE ANALYSIS SUMMARY
NERVA B-2 REACTOR

TABLE II

PAGE 1 of 9 PAGES
DATE 1-22-62 REV. 0

PART NAME	PLANNING PARTS LIST NUMBER	MODE OF FAILURE	HAZARD	EFFECT ON THRUST*	CAUSE OF FAILURE	RECOMMENDED METHODS TO ELIMINATE OR PREVENT FAILURE: TESTING MFG.	TESTING DEV.	DESIGN	DISPOSITION
Top Support Plate	D6.2.1.1.1	Shear at Outer Support Flange		None	Vib., Load, ΔT, Liq. H_2 Slug		E	Make certain Liq. H_2 never reaches core	
		Shear at Outer Support Flange		2 (No start)	Vib., Load, ΔT, Liq H_2 Slug		E	Make certain Liq. H_2 never reaches core	
		Crack or break between holes		5	Vib., Flow, ΔT, Liq. H_2 Slug	QC	E	Make certain Liq. H_2 never reaches core	
		Break - Longit.		5	Vib., ΔT, Liq. H_2 Slug	QC	E	Make certain Liq. H_2 never reaches core	
		Break - Trans.		None	Vib., T, ΔT, Liq. H_2 Slug		E	Make certain Liq. H_2 never reaches core	
		Break - Trans.		2 (No start)	Vib., T, ΔT, Liq. H_2 Slug		E	Make certain Liq. H_2 never reaches core	
		Seize - Ramp	X	1, 3	Vib., T., Load, Coef. Friction		E	Adequate Design	
Bottom Support Plate	D6.2.1.1.2	Shear at Outer Support Flange	X	1, 3	Vib., ΔT, Load, Flow	QC	E		
		Crack or Break Between Holes		None	Vib., ΔT		E		
		Break - Longit.		None	Vib., ΔT		E		
		Break - Trans.							
		Above Flange		None	Vib.		E		
		Below Flange	X	1, 3	Vib.		E		
		Vaporize	X	1, 3	Temp.		E		
		Shear - F.E.		5	Vib., Temp.		E		
		Seize - Ramp	X	1, 3	Vib., T., Load, Coef. Friction		E	Adequate Design	
Support Fuel Element	D6.2.1.1.3	Break - Trans.		None	Vib., T. Shock		E		
		Break - Longit.		5	Vib., T. Shock		E		
		Break - Longit.	X	2, 3	Vib., T. Shock, Errosion		E		
		Vaporize		5	T., Clogged Holes, Control Malfunction		E	Screen in inlet of core.	
Graphite	D6.2.1.1.4	Break - Trans.		None	Vib. Temp.		E		

*EFFECT ON THRUST

1. IMMEDIATE DESTRUCTION
2. EVENTUAL DESTRUCTION
3. DECREASE MORE THAN 30%
4. INCREASE
5. DECREASE LESS THAN 10%

[redacted]

FAILURE MODE ANALYSIS SUMMARY
NERVA B-2 REACTOR

TABLE II

PAGE 2 of 9 PAGES
DATE 1-22-62 REV 0

PART NAME	PLANNING PARTS LIST NUMBER	MODE OF FAILURE	HAZARD	EFFECT ON THRUST*	CAUSE OF FAILURE	RECOMMENDED METHODS TO ELIMINATE OR PREVENT FAILURE: TESTING MFG.	TESTING DEV.	DESIGN	DISPOSITION
		Break - Longit		None	Vib.,Temp.		E		
		Partially Vaporize		5	T.		E		
Fuel Element	D6 2 1 1 5	Crack coating		None	Bending distortion, flow	QC	E		
		Crack or break transverse		None	Vib , T.		E		
		Crack or break longitudinal	X	2, 3	Vib., T.		E		
		Crack between holes	X	2, 3	Vib., T.		E		
		Vaporize	X	2, 3	T., Clogged Passage, Control Malfunction		E	Failsafe control, protect core holes	
Filler Strip	D6 2 1 1 6	Break		None	Vib., T Shock	QC			
Pyrolytic Graphite Plates	D6 2 1 1 7	Break radially		None	Vib.,Expansion of Bottom Support, Sticking		E		
		Break - Circum	X	2, 3	Vib.,Expansion, Sticking		E		
		Become detached		None	Vib , Incorrect Cure	QC	E		
		Distortion during cure	X	2, 3	Realignment of internal crystals	QC	E		
		Pieces break off		None	Vib , T. Shock, Expansion,Assembly of Distorted P[illegible]	QC	E		
		Pieces break off	X	2, 3	Vib., T Shock, Expansion,Assembly of Distorted Parts				
Support Ring	D6 2 1 2 1	Break Longit		5	Vib , T. Shock		E	Protect cooling holes.	
		Break Longit	X	2, 3					
		Break Trans		None	Vib , Flow	QC	E		
		Break - High Temp Coating		None	Vib , T. Shock, Flow, Errosion	QC	E		
		Break in High Temp Coating	X	2, 3					

*EFFECT ON THRUST
1 IMMEDIATE DESTRUCTION
2 EVENTUAL DESTRUCTION
3 DECREASE MORE THAN 10%
4 INCREASE
5 DECREASE LESS THAN 10%

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WANL-TNR-042

FAILURE MODE ANALYSIS SUMMARY
NERVA B-2 REACTOR

TABLE II

PAGE 3 of 9 PAGES
DATE 1-23-62 REV 0

PART NAME	PLANNING PARTS LIST NUMBER	MODE OF FAILURE	HAZARD	EFFECT ON THRUST*	CAUSE OF FAILURE	RECOMMENDED METHODS TO ELIMINATE OR PREVENT FAILURE: TESTING MFG	TESTING DEV	DESIGN	DISPOSITION
		Overheat	X	2, 3	Hot spot, clogged cooling holes			Must keep cooling passages open	
Bottom Circumferential Load Ring	D6 2.1.2.2	Break Longit		None	Vib, Flow	QC	E		
		Break Trans		None	Vib, Flow	QC	E		
		Melt	X	2, 3	T, Clogged Cooling Passages		E	Make sure cooling passages do not clog	
Bottom Load Ring Segments	D6 2.1.2.3	Break Trans		None	Vib, Temp		E		
		Break - Longit		None	Vib, T		E		
		Vaporize	X	1, 3	T, Hot Spot, Control Malfunction, clogged cooling passages		E	Must keep cooling holes free. Failsafe control	
		Seize at Ramp	X	2, 3	Vib, T, Load, Coef. Friction		E	Adequate Design	
Reflector Cylinder Sector	D6 2.1.2.4	Break Longit Axial Gaps	X	2, 3	Vib., T		E	Provide overlap to prevent heat flow to reflector	
		Break Trans	X	2, 3	Vib, T		E		
		Seize at Ramps	X	2, 3	Vib, T, Load, Coef. of Friction		E	Adequate Design	
Pyrolytic Graphite Tiles	D6 2.1.2.5	Break Radially		None	Vib, Sticking to core		E		
		Break Circum		None	Vib, Expansion and sticking		E		
		Become detached		None	Vib, Incorrect curing process		E		
		Distort on during cure		None	Realignment of crystals during cure	QC			
		Pieces break off		None	Vib, T Shock, Expansion		E		
Top Load Ring Segments	D6 2.1.2.6	Break Trans		None	Vib, T		E		
		Seize at Ramp	X	2, 3	Vib, T, Load, Coef. of Friction		E	Adequate Design	
		Break Longit		None	Vib, T.		E		
Spring Support	D6 2.1.2.7	Break Trans		None	Vib., T, Flow	QC	E		
		Break Longit		None	Vib., T., Flow	QC	E		

*EFFECT ON THRUST

1. IMMEDIATE DESTRUCTION
2. EVENTUAL DESTRUCTION
3. DECREASE MORE THAN 30%
4. INCREASE
5. DECREASE LESS THAN 10%

[redacted]

FAILURE MODE ANALYSIS SUMMARY
NERVA B-2 REACTOR

TABLE II

PAGE 4 of 9 PAGES
DATE 1-23-62 REV 0

PART NAME	PLANNING PARTS LIST NUMBER	MODE OF FAILURE	HAZARD	EFFECT ON THRUST*	CAUSE OF FAILURE	RECOMMENDED METHODS TO ELIMINATE OR PREVENT FAILURE: TESTING MFG	TESTING DEV	DESIGN	GRND. SHOPS
Top Support Ring	D6 2 1 2 8	Break Trans		None	Vib, T, Flow	QC	E		
		Break Circ		None	Vib, T, Flow	QC	E		
		Break Axially		None	Vib, T, Flow	QC	E		
		Seize at Ramp		None	Vib, T, Load Coef. of Friction.		E	Adequate Design	
Top Circumferential Load Ring	D6 2 1 2 9	Break Axially		None	Vib, T, Flow		E	Make sure reflector support ring can carry load	
		Break Trans		None	Vib, T, Flow		E		
		Break Circum		None	Vib, T, Flow		E		
		Seize with Spring Support ring	X	2	Vib, T, Flow, Cleaning Action of H_2			Select combination of materials for anti-seize	
Segment Loading Spring	D6 2 1 2 10	Break		None	Vib, Flow	QC	E		
		Relax		None	T		E		
Reflector Load Spring	D6 2 1 2 11	Break	X	2, 3	Vib, Flow	QC	E	Provide seat and supports so if spring fails both parts are retained	
		Relax		None	T				
Spring Support Ring	D6 2 1 2 12	Break Axially		None	Vib, T, Flow	QC	E		
		Break Circ		None	Vib, T, Flow	QC	E		
		Break Trans		None	Vib, T, Flow	QC	E		
		Seize Top Circ Load Ring	X	2	Vib, T, Flow Cleaning Action of H_2			Select combination of materials for anti-seize	
Reflector Support Ring	D6 2 2 1.0	Shear at Flange		None	Vib, Load, T Shock		E		
		Break at Outer Edge of Ring		None	Vib, Load, T Shock		E		
		Break at Inner Edge of Ring	X	2, 3	Vib, Load, T Shock		E		
		Break at Retaining Groove	X	2, 3	Vib, Load, T Shock		E		
		Break Axial		None	Vib, Flow	QC	.		

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FAILURE MODE ANALYSIS SUMMARY
NERVA B-2 REACTOR

TABLE II

PAGE 5 of 9 PAGES
DATE 1-23-62 REV. 0

PART NAME	PLANNING PARTS LIST NUMBER	MODE OF FAILURE	HAZARD	EFFECT ON THRUST*	CAUSE OF FAILURE	RECOMMENDED METHODS TO ELIMINATE OR PREVENT FAILURE: TESTING MFG.	TESTING DEV.	DESIGN	DISPOSITION
		Distort	X	4, 5	T.				
Reflector Sector	D6 2.2.2.0	Split Longit.		None	Vib.		E		
		Split Longit.	X	2, 3, 4	Vib.		E		
		Split Trans.		None	Vib.		E		
		Distort		None	T., Interrupted Cooling Flow, Cooling Hole Clog.		E	Protect cooling holes.	
		Distort	X	2, 3, 4	T., Interrupted Cooling Flow, Cooling Hole Clog.		E	Protect cooling holes.	
Bottom Reflector Ring	D6.2.2.3.0	Break Axial		None	Vib.		E		
		Seize Bearing Race		None	Vib.,T.,Cleaning Action H_2		E	Use roller bearing, self-aligning bearing.	
		Seize Bearing Race	X	2, 3, 4	Vib.,T.,Cleaning Action H_2		E	Use roller bearing, self-aligning bearing.	
		Distort		None	T.		E	Sufficient clearance for distortion.	
		Distort	X	2, 3, 4	T.		E	Sufficient clearance for distortion.	
Dowel	D6.2.2.4.0	Omit at Assembly		None	Careless Assembly	QC			
		Omit at Assembly	X	2, 3, 4	Careless Assembly				
Dowel Pin	D6.2.2.5.0	Omit at Assembly		None	Careless Assembly	QC			
		Omit at Assembly	X	2, 3, 4	Careless Assembly				
Dowel Pin	D6.2.2.6.0	Omit at Assembly		None	Careless Assembly	QC			
		Omit at Assembly	X	2, 3, 4	Careless Assembly				
Through Bolt	D6 2.2.7.0	Break		None	Overtorqued Defective Material	QC	E		
		Loosen		None	Undertorqued T.	QC	E		
Lock Plate	D6.2.2.8.0	Break		None	Vib.,Flow				
Lock Cup	D6.2.2.9.0	Bolt Head Rotates		None	Improperly crimped	QC			
		Falls out of casting		None	Not properly spun into groove	QC			

*EFFECT ON THRUST

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[redacted]

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FAILURE MODE ANALYSIS SUMMARY
NERVA B-2 REACTOR

TABLE II

PAGE 6 of 9 PAGES
DATE 1-23-62 REV. 0

PART NAME	PLANNING PARTS LIST NUMBER	MODE OF FAILURE	HAZARD	EFFECT ON THRUST*	CAUSE OF FAILURE	RECOMMENDED METHODS TO ELIMINATE OR PREVENT FAILURE: TESTING MFG	TESTING DEV.	DESIGN	DISPO-SITION
Control Cylinder	D6.2.2.10.1	Break Longit.		None	Vib., Flow	QC	E		
		Break Trans.		None	Vib., Flow	QC	E		
		Distort		None	T., Hot Spot, Clogged cooling holes		E	Must have adequate clearance.	
		Distort	X	2, 3, 4	T., Hot Spot, Clogged cooling holes			Keep cooling holes open.	
Control Plate	D6.2.2.10.2	Crack		None	Vib.		E	Mount boral so it will not be stressed by distortion. It must not rattle End plate holes to be smaller than core holes.	
		Break		None	T. Shock., Distortion		E		
		Break	X	2, 3, 4	T. Shock., Distortion				
		Distort		None	T.		E		
		Distort	X	2, 3, 4	T.				
Control Cylinder Sleeve	D6.2.2.10.3	Break - Trans.		None	Vib., T., Flow	QC	E		
		Break - Trans.	X	2, 3, 4	Vib., T., Flow				
		Break - Longit.		None	Vib., T., Flow	QC	E		
		Break - Longit.	X	2, 3, 4					
		Distort		None	T.		E		
		Distort	X	2, 3, 4					
Spring	D6.2.2.10.4	Break		None	Vib., Flow	QC	E		
		Break	X	2, 3, 4					
		Relax		None	Temp.		E		
		Relax	X	2, 3, 4					
Bearing Shaft (Top)	D6.2.2.10.5	Break at bearing nut undercut		5	Incorrect torque, Vib.	QC	E	Cooling holes should be smaller in diameter than holes in core.	
		Break between bearing nut undercut and spline		5	Incorrect torque, Vib.	QC	E		
		Break at spline undercut		5	Incorrect torque, Vib.	QC	E		

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[redacted]

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FAILURE MODE ANALYSIS SUMMARY
NERVA B-2 REACTOR

TABLE II

PAGE 7 of 9 PAGES
DATE 1-25-62 REV 0

PART NAME	PLANNING PARTS LIST NUMBER	MODE OF FAILURE	HAZARD	EFFECT ON THRUST*	CAUSE OF FAILURE	RECOMMENDED METHODS TO ELIMINATE OR PREVENT FAILURE: TESTING MFG	TESTING DEV	DESIGN	DISPOSITION
		Crack between holes		None	Vib.		E		
Bearing Shaft (Bottom)	D6.2.2 10.6	Break at Snap Ring Groove	X	None	Vib.		E		
		Break at Inboard Side of Bearing		None	Vib		E		
		Rounded Groove Up		None	Snap Ring Assembly	QC			
Bearing	D6.2.2.11.0	Seize		None	T., Contamination, Cleaning Action H_2	QC	E		
		Seize	X	2	T., Contamination, Cleaning Action H_2	QC	E		
		Ball Breaks		None	Defective	QC		Provide screen in core.	
		Ball Breaks	X	2	Defective	QC		Provide screen in core.	
		Ball Retainer Breaks		None	Defective	QC		Provide screen in core.	
		Ball Retainer Breaks	X	2	Defective	QC		Provide screen in core.	
Snap Ring	D6.2.2.12.0	Not in Groove		None	Careless Assembly	QC			
Stop Plate	D6.2.2.13.0	Wear Keys	X	2, 4	Vib., Not retained axially and radially		E	Eliminate axial and radial play.	
		Break Stop Tab	X	2, 4	Vib., Flow	QC	E	Make certain stops are failsafe or provide backup stops.	
Stop Pin	D6.2 2.14.0	None		None	------	---	---		
Control Drum Return Spring	D6.2.2.15.0	Break	X	(Cannot Scram)	Flow, Dent Vib.	QC	E		
Spring Cover	D6.2.2.16.0	Break at Weld	X	2, 4	Bad Weld	QC		Spring and stop should be separately retained.	
Insert Heli-coil	D6.2.2.17.0	Pull Out		None	Insufficient thread engagement	QC			
Bearing Support	D6.2 2.18.0	Break at Thread	X	4, 5	Vib.,Flow	QC	E		
		Break Mounting Flange	X	4, 5	Vib.,Flow	QC	E		

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FAILURE MODE ANALYSIS SUMMARY
NERVA B-2 REACTOR

TABLE II

PAGE 8 of 9 PAGES
DATE 1-25-62 REV. 0

PART NAME	PLANNING PARTS LIST NUMBER	MODE OF FAILURE	HAZARD	EFFECT ON THRUST*	CAUSE OF FAILURE	RECOMMENDED METHODS TO ELIMINATE OR PREVENT FAILURE: TESTING MFG.	TESTING DEV	DESIGN	DISPO-SITION
Bolt	D6.2.2.19.0	Break		None	Vib		E		
Lock Cup	D6 2 2.20 0	Bolt Rotates		None	Improperly Crimped	QC	E	Provide screen in core inlet	
		Bolt Rotates	X	2, 4	Improperly Crimped	QC	E	Provide screen in core inlet.	
		Falls out of casting		None	Not spun into casting properly	QC	E		
		Falls out of casting	X	2, 4	Not spun into casting properly	QC	E		
Threaded Ring	D6.2.2.21.0	Break		None	Vib., Flow	QC	E		
Lockwasher	D6.2 2.22 0	Tab Not Bent Into Groove		None	Careless Assembly	QC	E		
Connector Shaft	D6 2.2.23.0	Break Between Splines		5	Vib., Flow	QC	E		
		Seize Spline		None	Vib., Contamination, Cleaning Action of H_2	QC	E		
Nut	D6.2.2.24.0	None		None	------	---	---		
Cup Washer	D6.2 2.25.0	Failure to Crimp		None	Careless Assembly	QC			
Dowel Pin	D6.2.2.26.0	Omit at Assembly	X	1, 4	Careless Assembly	QC		Redesign for means of orienting to eliminate separate loose piece.	
		Seizure		None	Contamination		E		
Floating Shaft	D6.2.2.27.0	Break		5	Vib., Overtorque	QC	E		
		Spline Seizure		None	Vib.		E		
Core Support Ring	D6 2.3 1.0	Break Radially		None	Vib., T. Shock, Flow	QC	E		
Core Support Ring Retaining Segments	D6.2.3.2.0	Break		None	Vib., T. Shock, Flow	QC	E		
Bolt	D6.2.3.3 0	Break		None	Vib., T.,		E		
Lock Cup	D6.2.3.4.0	Bolt Head Rotates		None	Improperly Crimped	QC		Design screen in inlet of core.	
		Bolt Head Rotates	X	1, 4, 5	Improperly Crimped	QC		Design Screen in inlet of core.	

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PART NAME	PLANNING PARTS LIST NUMBER	MODE OF FAILURE	HAZARD	EFFECT ON THRUST*	CAUSE OF FAILURE	RECOMMENDED METHODS TO ELIMINATE OR PREVENT FAILURE — TESTING MFG	TESTING DEV.	DESIGN	DISPOSITION
		Falls Out of Casting		None	Not properly spun into retaining hole	QC		Design Screen in inlet of core	
		Falls Out of Casting	X	1, 4, 5	Not properly spun into retaining hole	QC		Design Screen in inlet of core.	
Shield	D6.2.4.1.0	Break Mtg. Flg.	X	1, 3	Vib.		E	Make sure LiH cannot enter core.	
		Rupture LiH Capsule	X	1, 3	Faulty weld, weld leak, T., impurities, vib.	QC	E	Make sure LiH cannot enter core.	
		Cracks bottom plate		None	Vib., T., Faulty Weld	QC	E		
		Crack Top Plate		None	Vib., T., Faulty Weld	QC	E		
Baffle	D6.2.4.2.0	Weld Cracks		None	Vib., T., Faulty Weld	QC	E		
		Bellows Seal Rupture		None	Vib.		E		
		Parts Break Off		None	Continuation of Weld Cracks	QC	E		
		Distortion		None	Vib., T., P.		E		

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